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RADIOACTIVITY IN SURFACE WATERS OF THE COLUMBIA RIVER BASIN, 1958-1964

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RADIOACTIVITY IN SURFACE WATERS OF THE COLUMBIA RIVER BASIN 1958-1964

Water Quality Section
Basic Data Branch
Division of Water Supply and Pollution Control
Public Health Service
Department of Health, Education, and Welfare

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Levels of radioactivity in the surface waters of the Columbia River Basin are reported, with emphasis on the main stem below the AEC's Hanford Works near Pasco, Washington. Natural radioactivity in the Columbia Basin includes alpha activity which varies with suspended sediment concentrations and beta activity from potassium-40. Man-made radioactivity is added to surface waters by nuclear detonations and operation of the Hanford Works in the lower Columbia River. From October 1957 to September 1964, gross beta activity transport at Pasco was between 1500 and 5000 curies per day. No significant changes in radioactive loads were revealed during this period.

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Memorandum

PUBLIC HEALTH SERVICE - BSS

TO : Richard F. Poston, Officer-In-Charge
Pacific Northwest - DWSPC Activities
Region IX - Portland, Oregon

DATE: February 26, 1965

FROM : Chief, Basic Data Branch
Division of Water Supply and Pollution Control

SUBJECT: Report on Radioactivity Surveillance, Columbia River Basin

Forwarded herewith is a revision of the preliminary report presenting an interpretation of radioactivity surveillance data from the Water Pollution Surveillance System stations in the Columbia River Basin. The preliminary report was sent to you on January 5, 1965. Revisions included in this report reflect discussions and conclusions reached at a meeting in Cincinnati on February 16-17, 1965. Participants in the meeting included representation from this Branch, the Technical Services Branch, the Division of Radiological Health and the Hanford Works.

The most significant finding of this study is that throughout the period October 1957 to September 1964, gross beta activity transport at Pasco, Washington, was generally between 1,500 and 5,000 curies per day. While data on specific isotopes were not obtained, and while we must admit the limitations of gross radioactivity data, the Surveillance System findings reveal no significant changes during this period insofar as radioactive loads as measured are concerned. This does not exclude the possibility of significant changes in the concentrations of individual radioisotopes. It should be noted, also, that extreme values for gross radioactivity are occasionally found, and it must be assumed that these values represent above average quantities of discharged radioactivity.

I feel this report may be of some special use to the Columbia River Basin Project. Questions regarding the technical details of the material presented should be directed to Mr. Charles G. Gunnerson, In Charge, Data Utilization Studies, Water Quality Section, 1014 Broadway, Cincinnati, Ohio 45202, who was assigned the responsibility for its preparation.

Richard S. Green

Enclosure

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RADIOACTIVITY IN SURFACE WATERS OF THE COLUMBIA RIVER BASIN 1958-1964

Introduction

Levels of radioactivity in the surface waters of the United States have been determined by the Public Health Service in its water pollution surveillance program since 1957. Concentrations of radioactivity have been reported annually[1-6] and interpreted periodically for the United States[7,8,9]. The present study is restricted to the Columbia River basin with particular emphasis on the main stem below the AEC's Hanford Works.

Geography and Hydrology

The Columbia River basin includes 259,000 square miles of which about 3,000 square miles are in lakes, reservoirs, and channels. About 68 per cent of the area is forest or open range, 22 per cent is agricultural and 10 per cent is miscellaneous (cities, roads, etc.). Higher elevations are over 11,000 feet in the Cascade Range and about 12,000 feet in the Rocky Mountains. Temperatures vary annually from about 10° to 100° F along the coast and from -50° to 120° F in inland areas.

The 50-year mean flow of the Columbia River is 248,700 cfs which is equivalent to an annual runoff of 13.0 inches[10]. Tributary runoff varies from 3.4 inches in the interior to 76.2 inches near the coast.

There are extensive existing and proposed water resources developments in the basin; these are shown on Plate 1 at the end of this report.

Sources of Radioactivity in the Columbia Basin

Natural radioactivity in the Columbia basin includes alpha activity which varies with suspended sediment concentrations and beta activity from potassium-40. The alpha activity has been previously evaluated[8] and will not be further considered in this report.

Man-made radioactivity is added to surface waters by nuclear detonations and, in the lower Columbia River, by operations of the Hanford Works. Effects of the latter are, as expected, greatest at the nearest downstream sampling station, Pasco, Washington. Strontium-90 is due to fallout from nuclear tests. A mixture of radionuclides, particularly sodium-24, silicon-31, phosphorus-32, scandium-46, chromium-51, manganese-56, copper-64, zinc-65, zinc-69, gallium-72, arsenic-76, strontium-89, and neptunium-239, is discharged in the cooling and other waste waters[11,12,13,14,15] from Hanford.

Methods

Samples are collected at 14 water pollution surveillance stations in the Columbia River basin, of which four are located on the lower Columbia below the Hanford Works.

Locations are shown on the overlay to Plate 1.

Gross alpha activity, gross beta activity, and strontium-90 concentrations are determined in the Water Quality Section laboratories in Cincinnati, Ohio. Values of these activities in surface waters normally are not affected by decay between the sampling and analyses.

In the lower Columbia River, the mixed reactor wastes decay at such a rate that correction factors must be applied to observed values in order to evaluate conditions in the stream. These factors are discussed in a subsequent portion of this report.

The basic sampling program provided for weekly analyses of gross alpha and gross beta activities. Beginning in 1959, the strontium-90 analyses of total solids were made quarterly on three-month composites of aliquots from weekly samples. Beginning in November 1962, the frequency of analysis was reduced to two quarterly samples per year at each sampling point except those stations immediately below nuclear installations, where quarterly analyses were continued.

The analytical method used for determining gross alpha and beta radioactivity is described in the eleventh edition of "Standard Methods for the Examination of Water and Wastewater"[15]. Suspended and dissolved solids are separated by passing the sample through a membrane filter (type HA) with a pore size of 0.45 microns; planchets are then prepared for counting the dissolved solids (in the filtrate) and the suspended solids (on the charred filter membrane) in an internal proportional counter.

Through September 1961, the method used for determining strontium-90 was that described in the eleventh edition of Standard Methods[16]. Tri-

butyl phosphate was used to extract ingrown yttrium-90 from the purified, coprecipitated strontium-90. Beginning in October 1961, a modification of a procedure described by Harley has been used[17]. The yttrium-90 together with an yttrium carrier is coprecipitated at pH 8.5; the precipitate is washed, redissolved, and reprecipitated as yttrium oxalate and the latter is washed and counted in a low-background anticoincidence, end-window proportional counter.

Correction of Observed Levels of Gross Beta Activity in the Lower Columbia River

Routinely reported levels of radioactivity in the Columbia River[1-6] are not corrected for decay since the observed levels are considered reasonably representative of those in the Pasco municipal water distribution system. Annual average exposures due to these levels have been estimated to be well within the standards established by the National Council for Radiation Protection[11,12,13,14].

In order to assess radioactive waste discharges to the river, however, it is necessary to compute transport of radioactivity at various points downstream from the Hanford Works under all flow conditions. It is accordingly necessary that values be computed for the actual sampling time.

During the period 1960 to 1962, a total of 99 radioactivity samples from Pasco, which had originally been analysed within 1 to 3 weeks of sampling, were recounted after intervals of from 2 to 50 days in the Water Quality Section laboratory. These data permitted estimation of the decay rates for the corresponding periods. Additional data were obtained from the

Hanford staff[18] on 5 samples from Pasco which were counted at frequent intervals from 4 hours to 30 days after sampling. The PHS and Hanford data were plotted on semi-logarithmic paper, normalized to time zero (see below) and maximum, minimum and median decay rates determined.

All decay corrections are computed on the basis of time zero at Pasco. Travel times to McNary Dam at various flows were obtained from earlier PHS studies[19]. Travel times to sampling points further downstream were estimated from channel geometry and verified by successive approximations using beta activity decay rates computed for this study.

The adopted travel times, which are necessary for correction of all observed beta activities below Pasco, are listed on Table 1.

Table 2 presents the correction factors to be applied to samples collected at or below Pasco. It is not possible to compute radioactivity levels upstream from available data since neither the composition nor the decay rate of the original waste is known. These levels are, of course, higher than those reported herein.

The validity of the adopted travel times (Table 1) and decay correction factors (Table 2) are demonstrated by Figure 1. This figure shows that the decay rates in the river are essentially identical with median values for stored samples upon which the adopted correction factors were based. Use of either higher or lower correction factors results in differences between river and stored samples which increase with distance downstream.

The agreement between decay rates in the river and in stored samples shown in Figure 1 also suggests that biological uptake in the Columbia River

which has been studied intensively for a number of years[19,20] may be neglected in computations of gross beta activity balance.

Gross Beta Activity

Gross beta activity in the Columbia River basin, except for the main stem below Hanford, reflects natural (potassium-40) radioactivity and fallout from nuclear detonations. It has been previously shown that these levels are low and do not interfere with water utilization[8].

In the lower Columbia River, gross beta activities indicate pollution from the Hanford Works. Figure 2, which is based on Pasco data, shows the transport in curies per day for water years 1958-1964 during which there was a wide range of beta activity transport with no apparent seasonal or secular variations. Values ranged from 900 to 7,500 curies per day. A single sample (May 28, 1962) contained much more radioactivity than usual but is not regarded as representative of average river water radioactivity for that date.

The May 28, 1962 Sample. The estimated total gross beta activity at time of collection was 316,000 pc/l of which 98 per cent was in the suspended fraction. The suspended solids concentration was 35 mg/l, a typical value for Pasco, so that the specific gross beta activity was 9.0×10^6 pc/g. The dried sample was further examined with a 200-channel pulse-height analyzer with a 4 x 4 inch NaI (Tl activated) crystal. The spectrum indicated strong peaks for Cr-51, (Mn-54 + Ga-72 + Sc-46) and (Zn-65 + Co-60). All of these have been reported[11,13,14] as radioactive constituents in Hanford waste waters and several are beta emitters. P-32 is a much stronger beta emitter and a consistently important portion of the radioactivity at Pasco; however, a laboratory accident involving the May 28 sample made it

impossible to determine how much of the total activity was due to P-32. Accordingly, the identity of the specific radionuclides in the May 28, 1962 sample which resulted in the greatly increased radioactivity is unknown.

Since the activity was in the suspended fraction, it is assumed that it would have been removed by the Pasco water plant. This is substantiated by the results of analyses by Hanford personnel for specific isotopes in the treated water sampled on the same day[14]. It was indicated that radioactivity levels from rare earths plus yttrium, Na-24, P-32, Cr-51, Cu-64, Zn-65, As-76, Sr-89 plus Sr-90, I-131, and Np-239 were normal for that time of year.

The credibility of a single extreme observation of suspended beta activity is supported by the collection of a single unique bottom sediment sample about a year later at a point about 75 miles downstream from Pasco. This sample has been reported by Cutshall and Osterberg[21] to have contained a single angular "hot particle," 11 x 25 microns in size, of unknown origin, which exhibited a, "...fission product radioactivity...equivalent to that found in about 200 grams of average sediment from the same location." Assuming an intermediate value of 18 μ for the third dimension and density of 2.6, the ratio of specific activity in the hot particle to that in average sediment may be calculated as 1.5×10^{12}. The comparable ratio for the May 28, 1962 sample, assuming an average total beta activity of 13,000 pc/l (Figure 3), average suspended activity equal to ten per cent of the total (see Figure 5, below), and an average suspended solids concentration of 30 mg/l (see Figure 6, below) is 200. The latter figure is conservative in light of that for the Cutshall and Osterberg "hot particle". It is not

suggested that either the isotopic composition or the specific activities of the two events are comparable. The significant point here is that extreme values do occur on occasion in the lower Columbia River.

Typical Gross Beta Activity. Figure 3 presents estimated annual average transport and concentration values for Pasco. The May 28, 1962, data were not included. Concentrations show the effects of dilutions, so that relatively wet or dry years may be identified from the figure. Weighted average concentrations computed from PHS data vary somewhat from the calendar year averages reported by the AEC[12,13,14,15]. Owing to differences in sampling and analytical methodology, as well as the necessary time lapses between sample collection and analysis, precise comparison of gross beta information is not possible in this case, and the agreement between these sets of data is regarded as satisfactory. It is concluded from Figures 2 and 3 that there have been no significant annual variations or long-term trend changes in beta activity at Pasco. This does not exclude the possibility of some change in the concentrations of the individual radioisotopes.

Annual frequency distributions of beta transport provide further information on waste disposal operations at Hanford. These are shown on Figure 4 and summarized in Table 3.

Table 3

TOTAL BETA ACTIVITY TRANSPORT AT PASCO

Water Year	Curies per Day	
	Median	80% Range
1958	3600	2300 to 5200
1959	3000	1750 to 4250
1960	2950	1800 to 4050
1961	3250	1700 to 4800
1962	2500	1400 to 4300
1963	3300	1800 to 4750
1964	4050	2200 to 6000

The slopes of the frequency distribution curves are typically broken at about the 90-percentile value, indicating that two populations or types of events are shown by the array of data. The lower group of values reflects usual or normal radioactive waste loads. The higher group represents out-of-ordinary events that occur about 10 per cent of the time.

Suspended Beta Activity. Figure 5 shows the per cent of gross beta which was in the suspended fraction. It was found, when samples were recounted, that this percentage remained essentially constant so that the decay rates for the suspended and dissolved fractions were thus identical. Figure 5 reveals a distinct annual variation with the higher and lower percentages occurring during the spring and fall months, respectively. This variation is not a function of the suspended sediment load; Figure 6

shows that the portion of beta activity which is suspended cannot be related to the concentration of suspended solids. This effect may well be the result of changes in the water chemistry, although seasonal changes in the biota should not be overlooked.

It is well known that concentrations of dissolved minerals vary inversely with the flow in natural streams. Although this relationship is not strictly true, particularly in the Columbia basin, because of seasonal variations in rainfall and in weathering or leaching rates, it is a useful approximation. This inverse relationship is distorted by impoundment, and may be entirely eliminated by complete flow regulation where storage times are of the order of a year. The wide variety in dam and reservoir developments in the Columbia River basin is immediately apparent from inspection of Plate 1. The quality of discharges from the larger reservoirs is a complex function of inflow quantity and quality; storage time; longitudinal, lateral and vertical mixing; and biological and bacteriological activity in the reservoir.

The degree of inverse flow-quality relationships on the Columbia River depends upon the relative proportions of unregulated and regulated flows at a particular point. In the lower reach of the river, the unregulated portions are sufficiently important to cause a definite annual cycle in dissolved solids concentrations. These concentrations are, in general, more dilute during periods of higher flows.

In addition to the concentration, the composition of dissolved minerals also varies seasonally. Silker[22] has recently examined seasonal changes in concentrations of Na, Cu, Mn, As, La, U, Zn, Fe, Co, Sc, P, and S in filtered samples from the Columbia River above Hanford. These changes were

compared with hydrographs of the upstream main stem and tributaries. Although the data showed considerable scatter, Silker was able to identify source waters for several of the elements. Corresponding changes in composition may, of course, be expected in the suspended fraction since the two are near equilibrium at any given time[23,24,25].

It appears likely that seasonal changes in chemical composition of dissolved and suspended solids and in concentrations of dissolved solids are responsible for the observed variations in the relative amounts of suspended and dissolved beta activity.

Strontium-90

Strontium-90, as previously noted, results from nuclear detonations. Both the PHS and AEC data indicate no measurable contribution of SR-90 to the lower Columbia River by the Hanford Works. Figure 7 shows average concentrations for the Columbia River basin and the conterminous United States. The lower values for the former are consistent with those previously reported[9], and show the general effects of precipitation and wind patterns.

Summary

The Public Health Service has monitored radioactivity since October 1957 in surface waters of the Columbia basin.

Gross beta activity throughout the basin reflects, to a minor degree, nuclear weapons testing. In the lower Columbia River, large quantities of beta activity are discharged in waste waters from the Atomic Energy Commission's Hanford Works. At Pasco, Washington, the gross beta transport during water years 1958 through 1964 was generally between 1,500 and 5,000 curies per day. About 10 per cent of the time, higher values due to unusual events were observed. Although there were wide variations during the period, there

were no significant changes in transport indicating that Hanford waste loads, as measured, have not changed significantly. An extreme value of 316,000 pico-curies per liter of gross beta activity was calculated for one sample (May 28, 1962), but this is not regarded as representative of the total river flow. Normally the suspended activity varies from 5 to 8 per cent of the total during late summer and early fall to from 15 to 20 per cent during the late spring, presumably due to changes in the composition of suspended and dissolved solids and in dissolved solids concentrations. The data indicate that biological uptake was not a significant factor in decay and transport of gross beta activity in the lower Columbia River.

Strontium-90 in surface waters of the Columbia River basin was due to fallout and, because of the local meteorological patterns, was found at lower levels than the average for the rest of the conterminous United States.

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Table 1

ESTIMATED TRAVEL TIMES FROM PASCO

TO

LOWER COLUMBIA RIVER WATER POLLUTION SURVEILLANCE STATIONS

Flow at Downstream Station (1000 cfs)	McNary Dam (days)	Bonneville Dam (days)	Clatskanie (days)
70	6.1		
80	5.8	13	
90	5.5	11	
100	5.3	10	32
110	5.1	9	30
120	4.8	8	27
130	4.6	7	25
140	4.4	7	23
150	4.2	6	22
160	4.0	6	20
170	3.8	6	18
180	3.6	6	16
190	3.5	5	15
200	3.3	5	14
210	3.2	5	12
220	3.0	5	11
230	2.9	4	10
240	2.7	4	9
250	2.6	4	7
260	2.5	4	7
270	2.3	3	6
280	2.2	3	5
290	2.1	3	5
300	2.0	3	4
310	1.9	2	4
320	1.8	2	4
330	1.7	2	3
340	1.6	2	3
350	1.6	2	3
360	1.5	2	3
370	1.5	2	3
380	1.5	2	3
390	1.4	2	3
400	1.4	2	3
410	1.4	2	3
420	1.4	2	3
430	1.4	2	3
440	1.4	2	3
450	1.4	2	3
460	1.4	2	3
470	1.3	2	3
480	1.3	2	3
490	1.3	2	3
500	1.3	2	3

Table 2

BETA ACTIVITY CORRECTION FACTORS

Columbia River

Lag, days	Travel Time From Pasco - Days																		
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	2.10	1.75	1.49	1.38	1.27	1.18	1.15	1.12	1.10	1.08	1.06	1.06	1.05	1.03	1.04	1.04	1.04	1.04	1.04
2	3.68	2.62	2.06	1.75	1.50	1.36	1.29	1.23	1.19	1.15	1.12	1.11	1.09	1.07	1.07	1.07	1.07	1.07	1.07
3	5.50	3.60	2.62	2.07	1.73	1.53	1.42	1.34	1.26	1.21	1.17	1.14	1.12	1.11	1.10	1.11	1.11	1.11	1.11
4	7.58	4.58	3.09	2.38	1.94	1.68	1.54	1.41	1.33	1.27	1.21	1.18	1.16	1.14	1.14	1.14	1.14	1.14	1.14
5	9.61	5.40	3.56	2.68	2.13	1.82	1.63	1.49	1.39	1.31	1.25	1.23	1.20	1.18	1.18	1.19	1.19	1.19	1.19
6	11.4	6.23	4.00	2.94	2.30	1.93	1.72	1.57	1.44	1.36	1.30	1.26	1.24	1.22	1.23	1.22	1.22	1.22	1.22
7	13.1	7.00	4.38	3.18	2.44	2.03	1.80	1.62	1.49	1.41	1.34	1.31	1.28	1.27	1.26	1.26	1.26	1.26	1.26
8	14.7	7.68	4.75	3.37	2.58	2.13	1.86	1.68	1.55	1.45	1.39	1.35	1.33	1.31	1.30	1.30	1.30	1.30	1.30
9	16.1	8.32	5.04	3.56	2.70	2.20	1.93	1.74	1.59	1.51	1.43	1.41	1.37	1.35	1.34	1.34	1.34	1.34	1.34
10	17.5	8.81	5.30	3.73	2.80	2.28	2.00	1.79	1.65	1.55	1.49	1.45	1.42	1.39	1.39	1.39	1.39	1.39	1.39
11	18.5	9.30	5.57	3.86	2.89	2.36	2.06	1.86	1.70	1.62	1.53	1.49	1.46	1.44	1.43	1.43	1.43	1.43	1.43
12	19.5	9.75	5.76	3.99	3.00	2.43	2.14	1.91	1.77	1.66	1.58	1.54	1.51	1.49	1.49	1.48	1.48	1.48	1.48
13	20.5	10.1	5.96	4.13	3.08	2.52	2.20	1.99	1.82	1.71	1.64	1.59	1.56	1.53	1.52	1.52	1.52	1.52	1.52
14	21.2	10.4	6.18	4.25	3.20	2.60	2.29	2.04	1.88	1.77	1.68	1.65	1.61	1.59	1.57	1.56	1.56	1.56	1.56
15	22.1	10.8	6.35	4.41	3.30	2.71	2.36	2.12	1.94	1.82	1.74	1.70	1.66	1.63	1.63	1.62	1.62	1.62	1.62
16	22.8	11.1	6.60	4.55	3.44	2.78	2.43	2.18	2.00	1.89	1.80	1.75	1.71	1.68	1.68	1.68	1.68	1.68	1.68
17	23.4	11.5	6.80	4.74	3.53	2.88	2.52	2.24	2.08	1.95	1.86	1.80	1.77	1.73	1.73	1.73	1.73	1.73	1.73
18	24.5	11.9	7.08	4.86	3.64	2.98	2.59	2.33	2.14	2.02	1.91	1.86	1.82	1.79	1.79	1.79	1.79	1.79	1.79
19	25.0	12.4	7.27	5.02	3.78	3.06	2.68	2.40	2.21	2.07	1.97	1.92	1.88	1.85	1.84	1.84	1.84	1.84	1.84
20	26.0	12.7	7.51	5.20	3.88	3.18	2.75	2.48	2.26	2.14	2.03	1.98	1.94	1.91	1.90	1.90	1.90	1.90	1.90
21	26.8	13.1	7.77	5.35	4.03	3.27	2.86	2.54	2.34	2.20	2.10	2.04	2.00	1.97	1.97	1.97	1.97	1.97	1.97
22	27.8	13.6	8.00	5.55	4.15	3.38	2.94	2.64	2.42	2.28	2.16	2.11	2.06	2.04	2.04	2.04	2.04	2.04	2.04
23	28.4	14.0	8.30	5.73	4.29	3.46	3.04	2.71	2.50	2.35	2.24	2.18	2.14	2.11	2.11	2.11	2.11	2.11	2.11
24	29.6	14.5	8.55	5.91	4.40	3.58	3.12	2.80	2.58	2.42	2.30	2.26	2.22	2.18	2.18	2.18	2.18	2.18	2.18
25	30.5	15.0	8.83	6.07	4.56	3.68	3.23	2.90	2.66	2.50	2.39	2.34	2.29	2.26	2.26	2.26	2.26	2.26	2.26
26	31.4	15.5	9.07	6.28	4.69	3.82	3.34	2.98	2.74	2.59	2.48	2.42	2.37	2.34	2.33	2.33	2.33	2.33	2.33
27	32.4	15.9	9.39	6.46	4.84	3.94	3.44	3.08	2.84	2.68	2.56	2.50	2.46	2.42	2.40	2.40	2.40	2.40	2.40
28	33.4	16.4	9.65	6.69	5.00	4.06	3.56	3.19	2.94	2.78	2.65	2.58	2.54	2.49	2.48	2.48	2.48	2.48	2.48
29	34.3	16.9	9.98	6.90	5.16	4.19	3.68	3.30	3.05	2.87	2.74	2.68	2.61	2.57	2.56	2.56	2.56	2.56	2.56
30	35.6	17.5	10.3	7.11	5.33	4.35	3.81	3.42	3.15	2.97	2.84	2.76	2.70	2.65	2.66	2.66	2.66	2.66	2.66
31	36.7	18.0	10.6	7.34	5.52	4.50	3.95	3.54	3.26	3.07	2.92	2.84	2.78	2.74	2.73	2.73	2.73	2.73	2.73
32	37.8	18.6	11.0	7.61	5.71	4.66	4.07	3.66	3.37	3.16	3.01	2.94	2.88	2.84	2.82	2.80	2.80	2.80	2.80
33	39.0	19.2	11.4	7.88	5.91	4.81	4.21	3.78	3.47	3.26	3.11	3.04	2.98	2.92	2.90	2.88	2.88	2.88	2.88
34	40.4	19.9	11.8	8.15	6.12	4.98	4.36	3.90	3.58	3.37	3.22	3.14	3.06	3.03	3.00	3.00	3.00	3.00	3.00
35	41.8	20.6	12.2	8.43	6.32	5.15	4.50	4.02	3.70	3.48	3.32	3.23	3.18	3.10	3.10	3.08	3.08	3.08	3.08
36	43.3	21.4	12.6	8.72	6.54	5.31	4.64	4.15	3.82	3.60	3.42	3.35	3.26	3.21	3.19	3.17	3.17	3.17	3.17
37	44.8	22.0	13.0	9.01	6.74	5.47	4.78	4.30	3.96	3.71	3.55	3.44	3.37	3.30	3.29	3.27	3.27	3.27	3.27
38	46.3	22.8	13.5	9.29	6.95	5.65	4.95	4.45	4.07	3.85	3.64	3.56	3.46	3.41	3.39	3.38	3.38	3.38	3.38
39	47.9	23.6	13.9	9.58	7.18	5.84	5.12	4.57	4.22	3.95	3.76	3.65	3.58	3.50	3.50	3.50	3.50	3.50	3.50
40	49.5	24.3	14.3	9.89	7.42	6.05	5.26	4.74	4.33	4.08	3.86	3.78	3.68	3.62	3.60	3.59	3.59	3.59	3.59
41	51.0	25.0	14.8	10.2	7.68	6.21	5.46	4.86	4.48	4.19	4.00	3.88	3.80	3.76	3.72	3.71	3.71	3.71	3.71
42	52.7	25.9	15.3	10.6	7.90	6.45	5.60	5.03	4.60	4.34	4.11	4.00	3.94	3.85	3.83	3.83	3.83	3.83	3.83
43	54.4	26.8	15.8	10.9	8.19	6.62	5.79	5.16	4.75	4.45	4.24	4.15	4.04	3.98	3.96	3.96	3.96	3.96	3.96
44	56.1	27.7	16.3	11.3	8.40	6.85	5.95	5.34	4.88	4.60	4.40	4.26	4.18	4.10	4.08	4.08	4.08	4.08	4.08
45	58.1	28.4	16.9	11.6	8.69	7.03	6.15	5.49	5.05	4.77	4.51	4.41	4.30	4.24	4.23	4.23	4.23	4.23	4.23
46	59.8	29.6	17.3	12.0	9.22	7.26	6.32	5.67	5.23	4.89	4.67	4.52	4.45	4.37	4.37	4.37	4.37	4.37	4.37
47	62.0	30.3	17.9	12.3	9.48	7.47	6.54	5.88	5.36	5.07	4.80	4.69	4.59	4.52	4.51	4.51	4.51	4.51	4.51
48	63.6	31.4	18.4	12.7	9.80	7.71	6.77	6.03	5.56	5.20	4.96	4.84	4.74	4.69	4.66	4.64	4.64	4.64	4.64
49	65.8	32.2	19.0	13.1	10.2	8.00	6.95	6.25	5.71	5.39	5.13	5.00	4.92	4.84	4.82	4.80	4.80	4.80	4.80
50	67.5	33.2	19.6	13.5	10.4	8.20	7.19	6.41	5.91	5.55	5.30	5.20	5.08	4.98	4.97	4.96	4.96	4.96	4.96
51	69.8	34.2	20.2	14.0	10.8	8.50	7.39	6.64	6.10	5.74	5.50	5.36	5.22	5.15	5.14	5.13	5.13	5.13	5.13
52	71.8	35.3	20.9	14.4	11.1	8.73	7.65	6.85	6.30	5.96	5.67	5.51	5.40	5.30	5.28	5.27	5.27	5.27	5.27
53	74.2	36.6	21.4	14.9	11.5	9.03	7.89	7.08	6.54	6.15	5.83	5.70	5.56	5.50	5.46	5.4	5.46	5.46	5.46
54	76.9	37.6	22.2	15.3	11.8	9.33	8.15	7.35	6.74	6.33	6.03	5.87	5.76	5.65	5.63	5.62	5.62	5.62	5.62
55	78.9	38.9	22.8	15.8	12.2	9.63	8.46	7.58	6.94	6.54	6.22	6.09	5.93	5.84	5.82	5.80	5.80	5.80	5.80
56	81.7	39.9	23.6	16.3	12.7	10.0	8.74	7.80	7.17	6.74	6.44	6.25	6.12	6.07	6.02	6.00	6.00	6.00	6.00
57	84.0	41.4	24.4	16.8	13.1	10.3	8.99	8.07	7.39	6.98	6.62	6.46	6.37	6.23	6.20	6.19	6.19	6.19	6.19
58	86.8	42.7	25.2	17.5	13.5	10.6	9.30	8.30	7.66	7.18	6.84	6.72	6.53	6.42	6.41	6.41	6.41	6.41	6.41
59	89.6	44.1	26.2	18.0	13.9	11.0	9.56	8.60	7.86	7.41	7.11	6.89	6.74	6.63	6.61	6.60	6.60	6.60	6.60
60	92.6	45.8	27.0	18.6	14.4	11.3	9.91	8.84	8.13	7.71	7.30	7.11	6.95	6.85	6.82	6.79	6.79	6.79	6.79
61	96.1	47.2	27.8	19.2	14.9	11.7	10.2	9.15	8.46	7.90	7.53	7.34	7.20	7.05	7.03	7.00	7.00	7.00	7.00
62	99.3	48.6	28.7	19.8	15.3	12.0	10.5	9.50	8.66	8.16	7.78	7.59	7.40	7.26	7.23	7.19	7.19	7.19	7.19
63	102.0	50.2	29.6	20.5	15.8	12.4	10.9	9.74	8.95	8.42	8.04	7.80	7.62	7.49	7.48	7.46	7.46	7.46	7.46
64	105.5	51.8	30.6	21.0	16.4	12.9	11.2	10.1	9.24	8.71	8.26	8.04	7.85	7.72	7.69	7.67	7.67	7.67	7.67
65	108.8	53.6	31.5	21.8	16.8	13.3	11.6	10.4	9.55	8.95	8.51	8.29	8.10	7.98	7.95	7.93	7.93	7.93	7.93

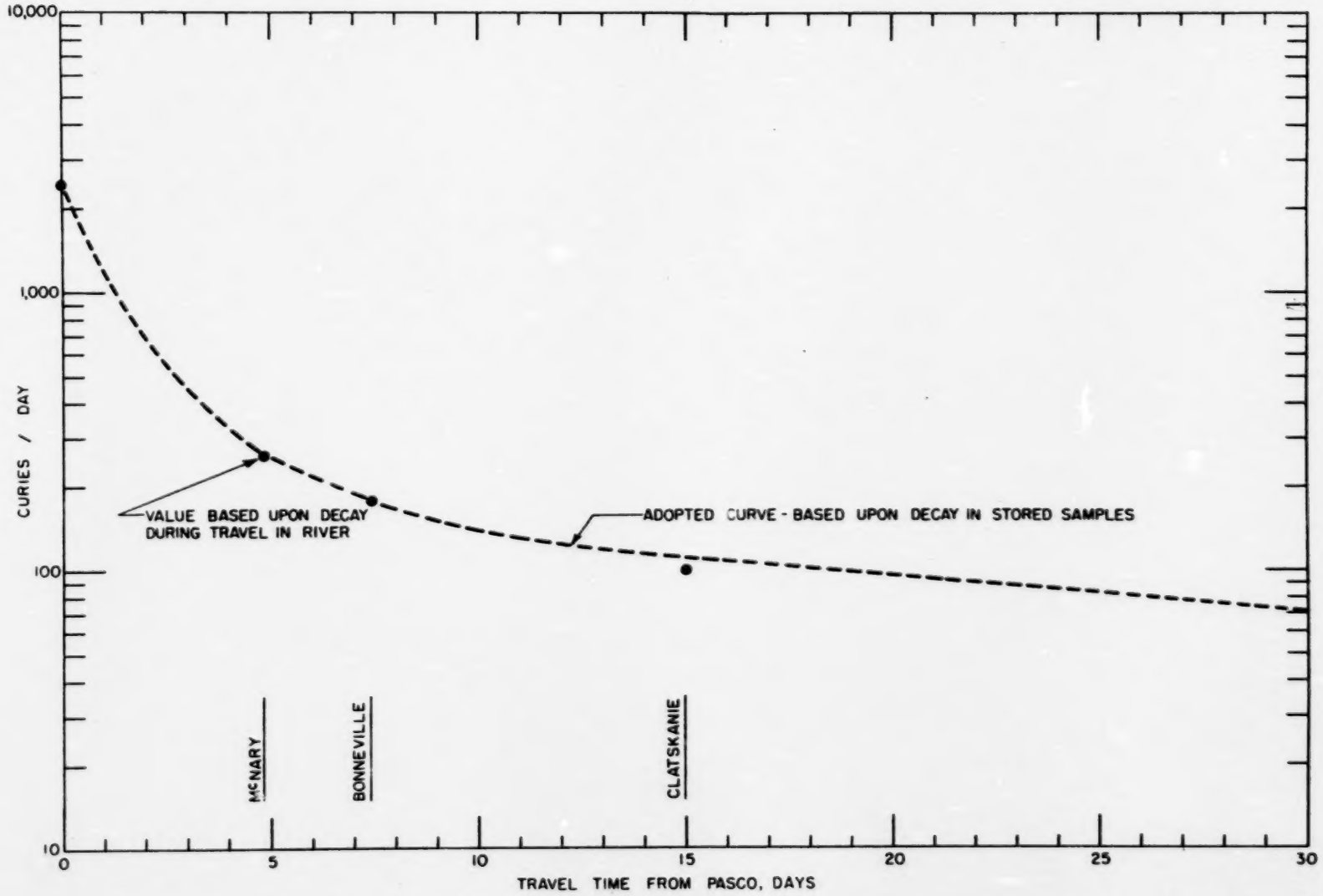


Figure 1. GROSS BETA ACTIVITY DECAY IN LOWER COLUMBIA RIVER AND IN STORED SAMPLES

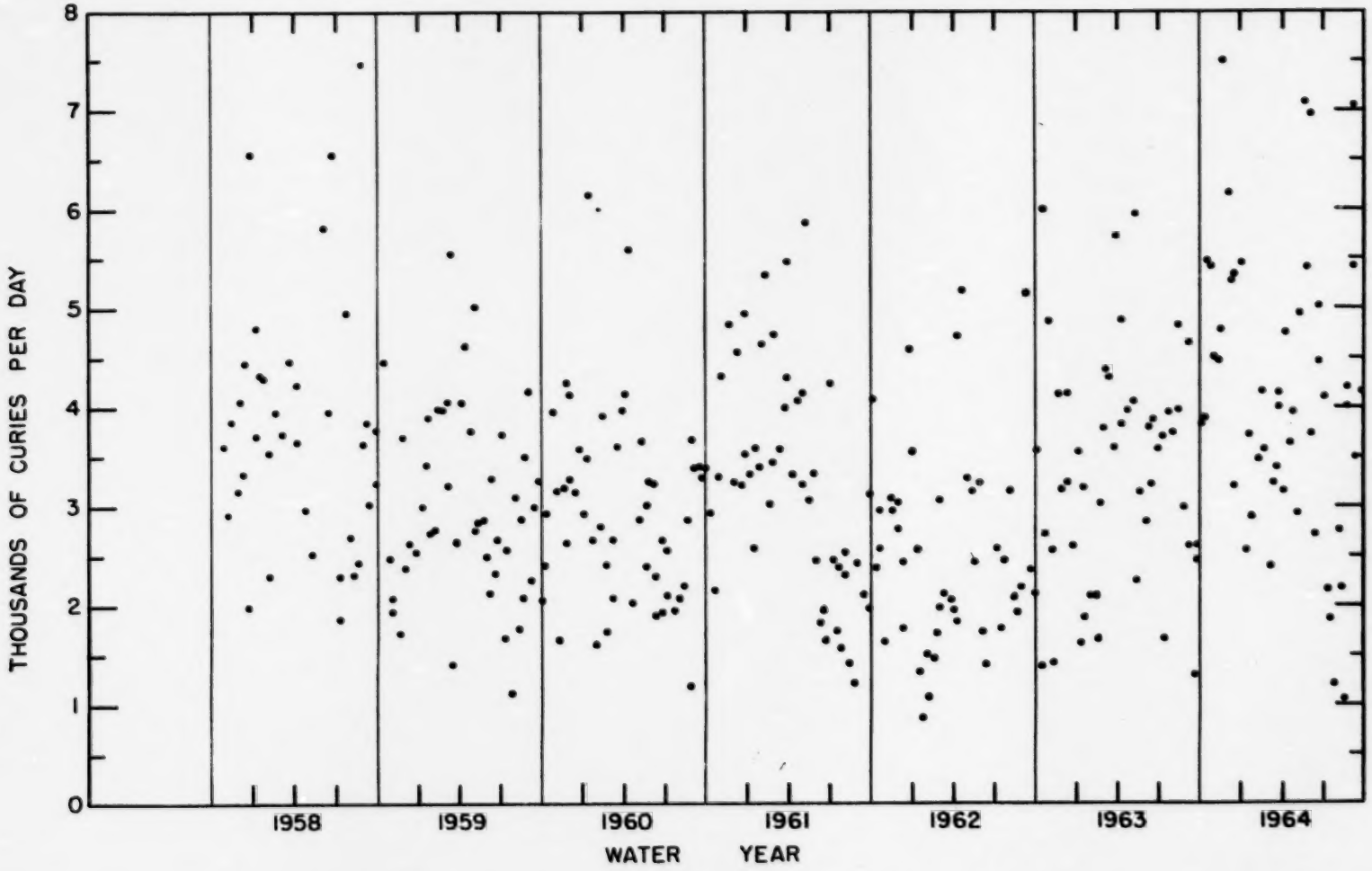


Figure 2. GROSS BETA ACTIVITY TRANSPORT, COLUMBIA RIVER AT PASCO 1958 - 1964

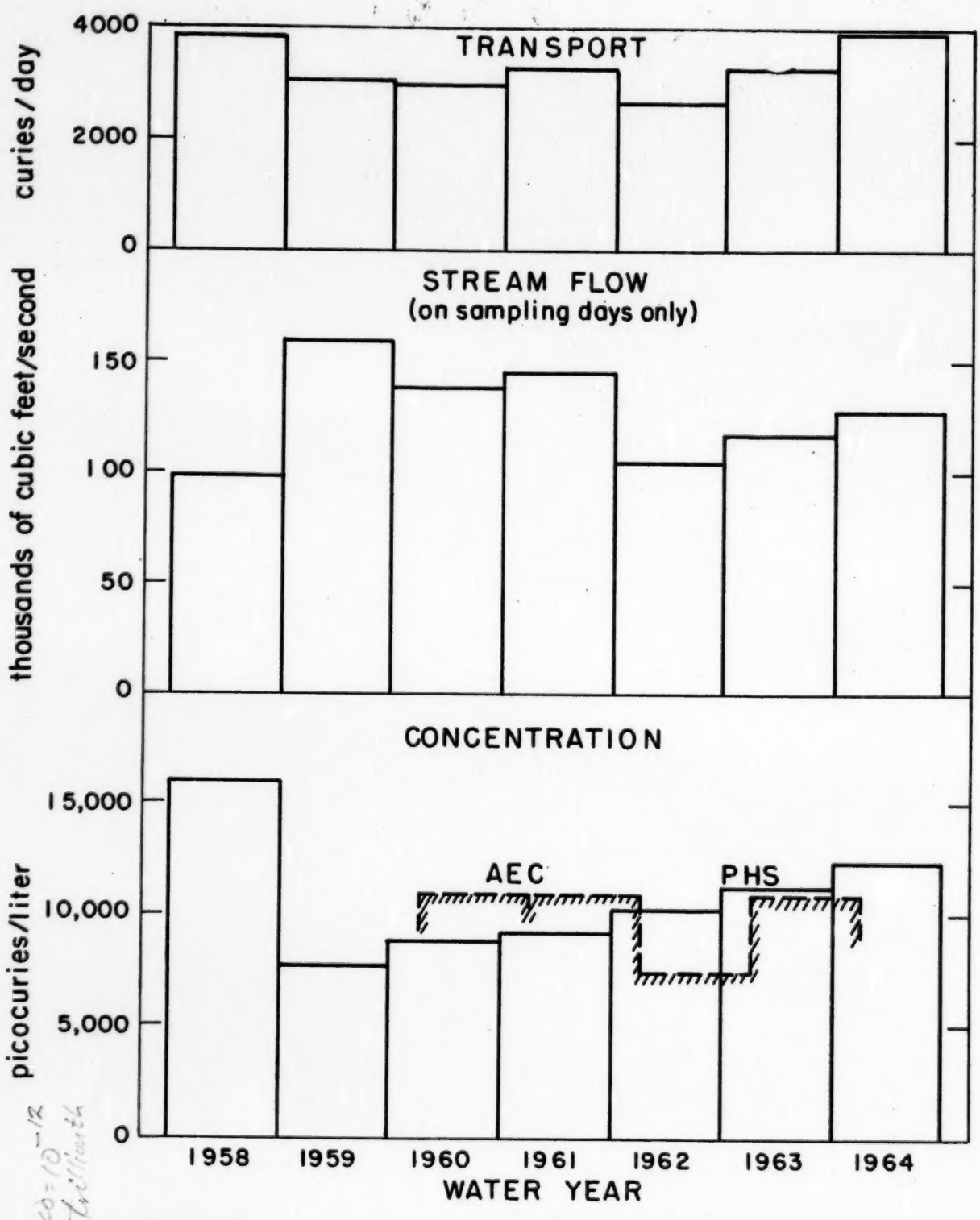


Figure 3. Average concentration and daily transport of gross beta activity, Columbia River at Pasco, 1958 - 1964

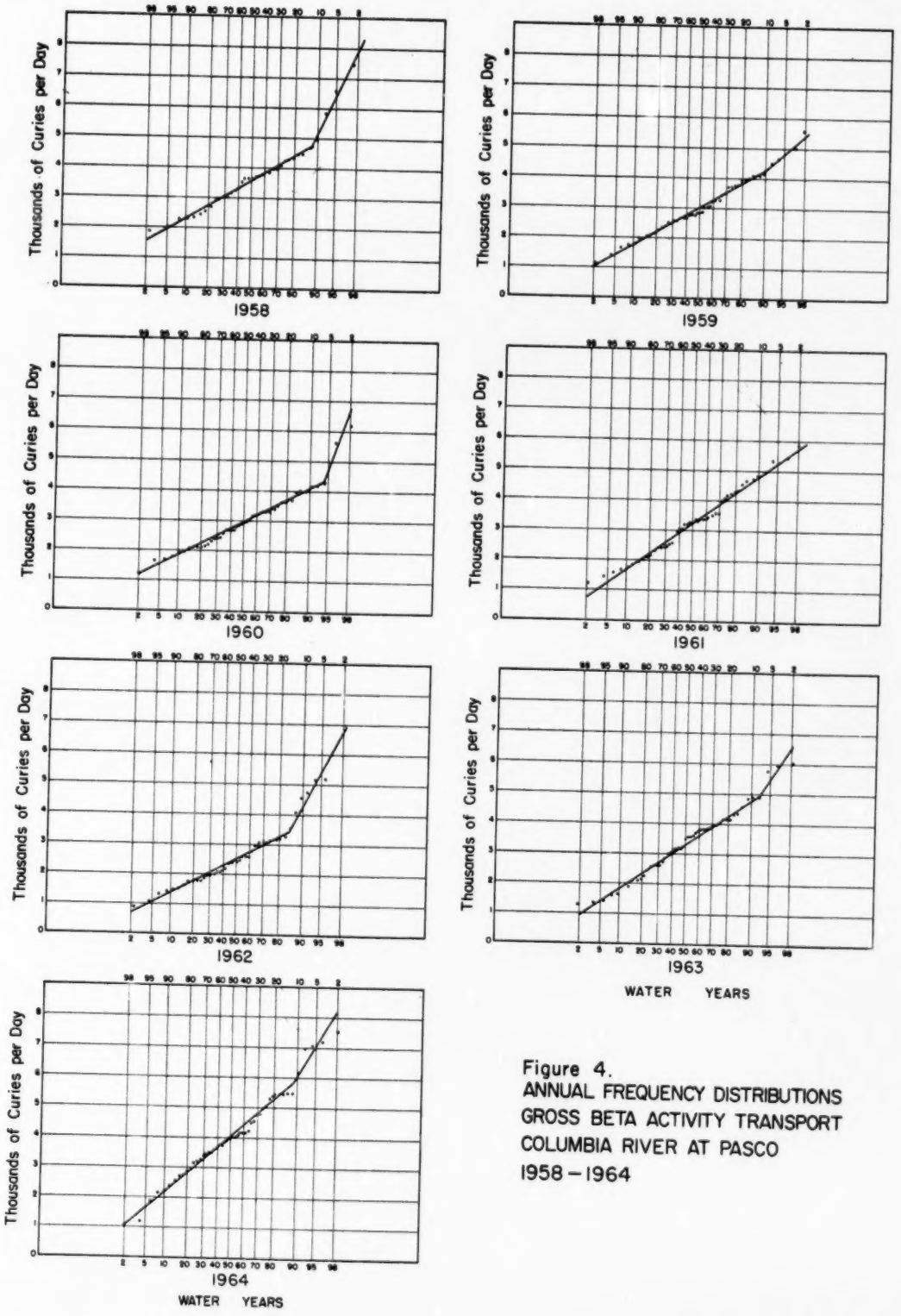


Figure 4.
ANNUAL FREQUENCY DISTRIBUTIONS
GROSS BETA ACTIVITY TRANSPORT
COLUMBIA RIVER AT PASCO
1958 – 1964

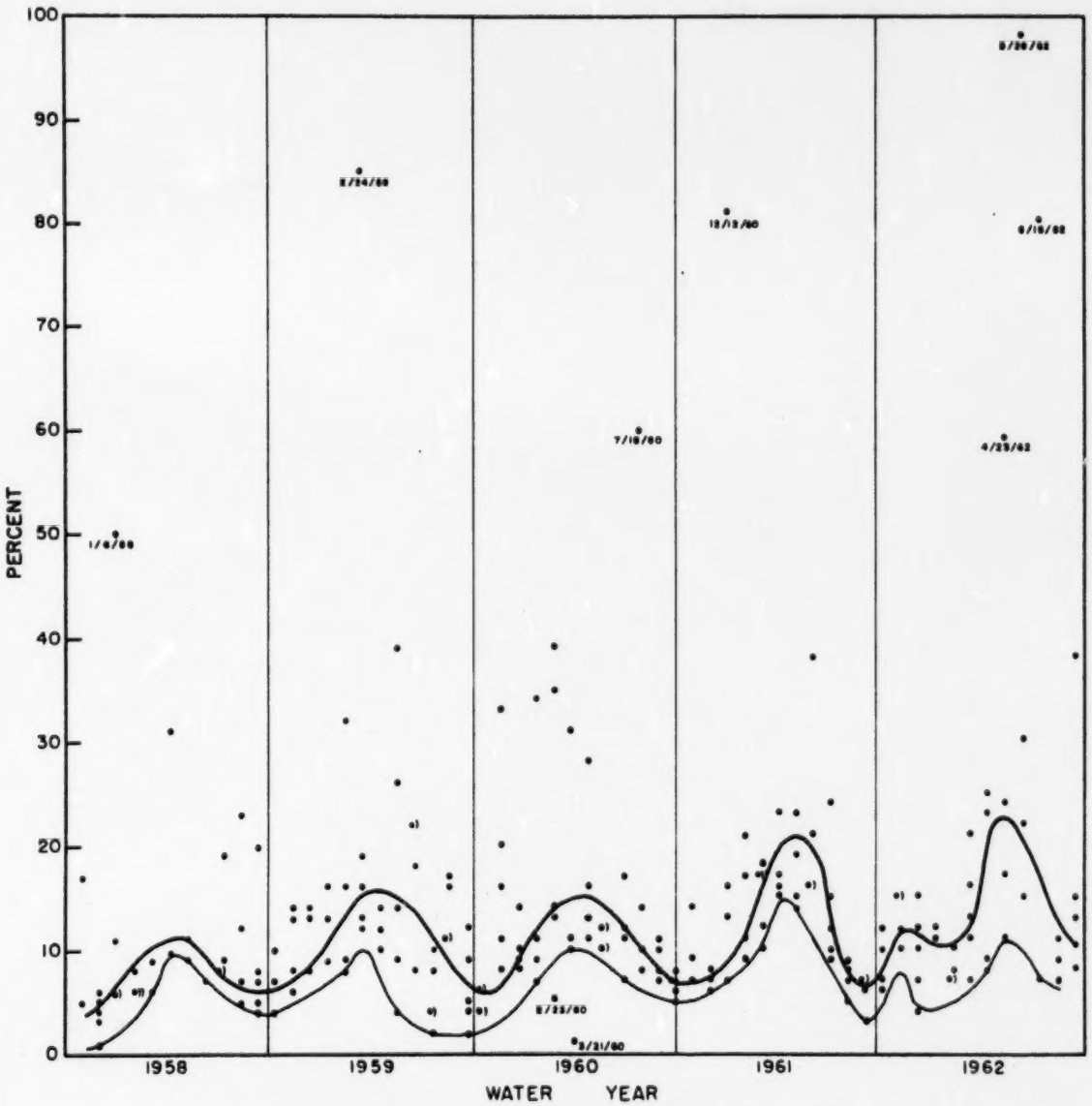


Figure 5. PERCENT SUSPENDED BETA ACTIVITY
COLUMBIA RIVER AT PASCO, 1958 - 1962

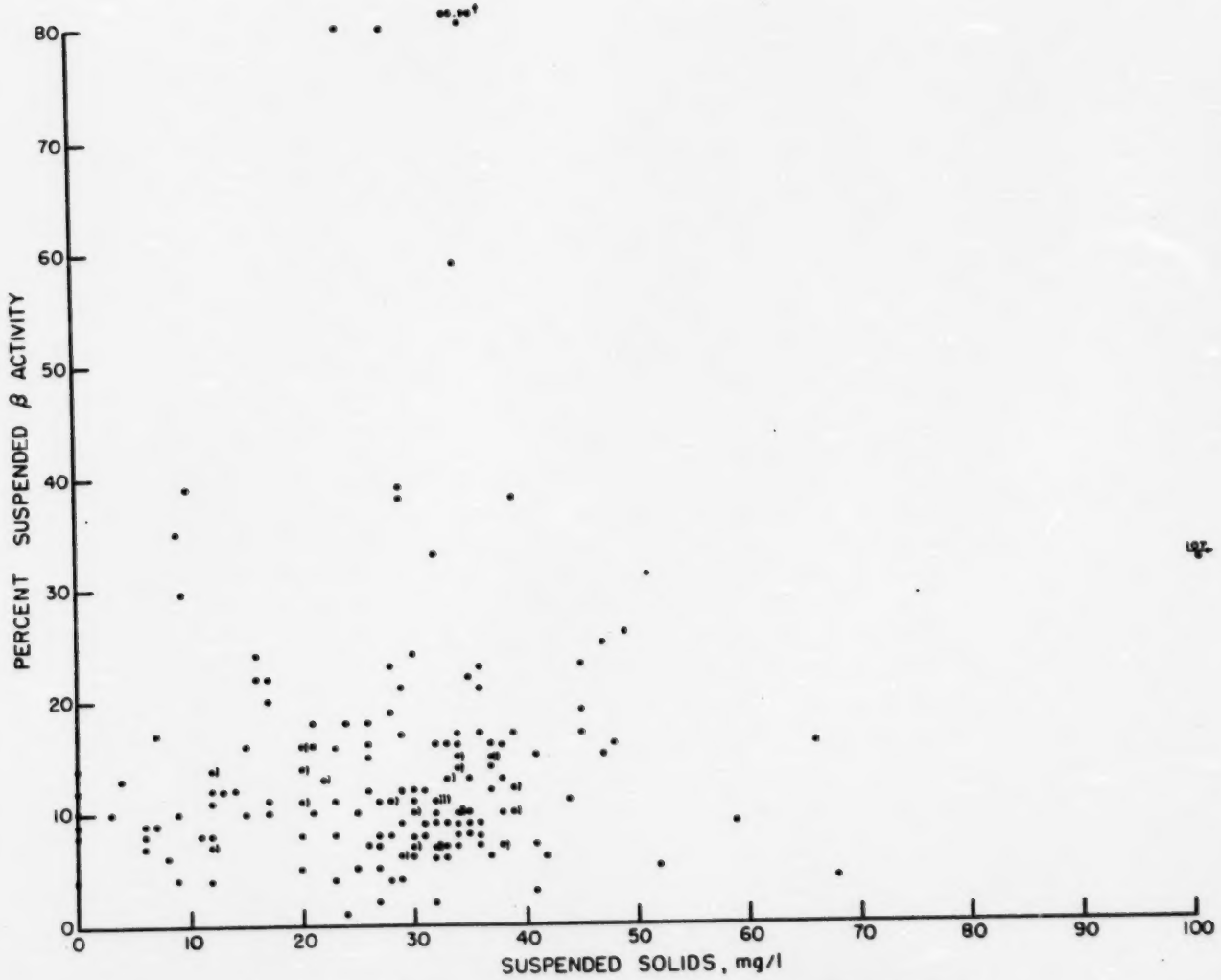


Figure 6. COMPARISON OF PERCENT SUSPENDED BETA ACTIVITY WITH SUSPENDED SOLIDS CONCENTRATIONS, COLUMBIA RIVER AT PASCO, WATER YEAR 1959-1962

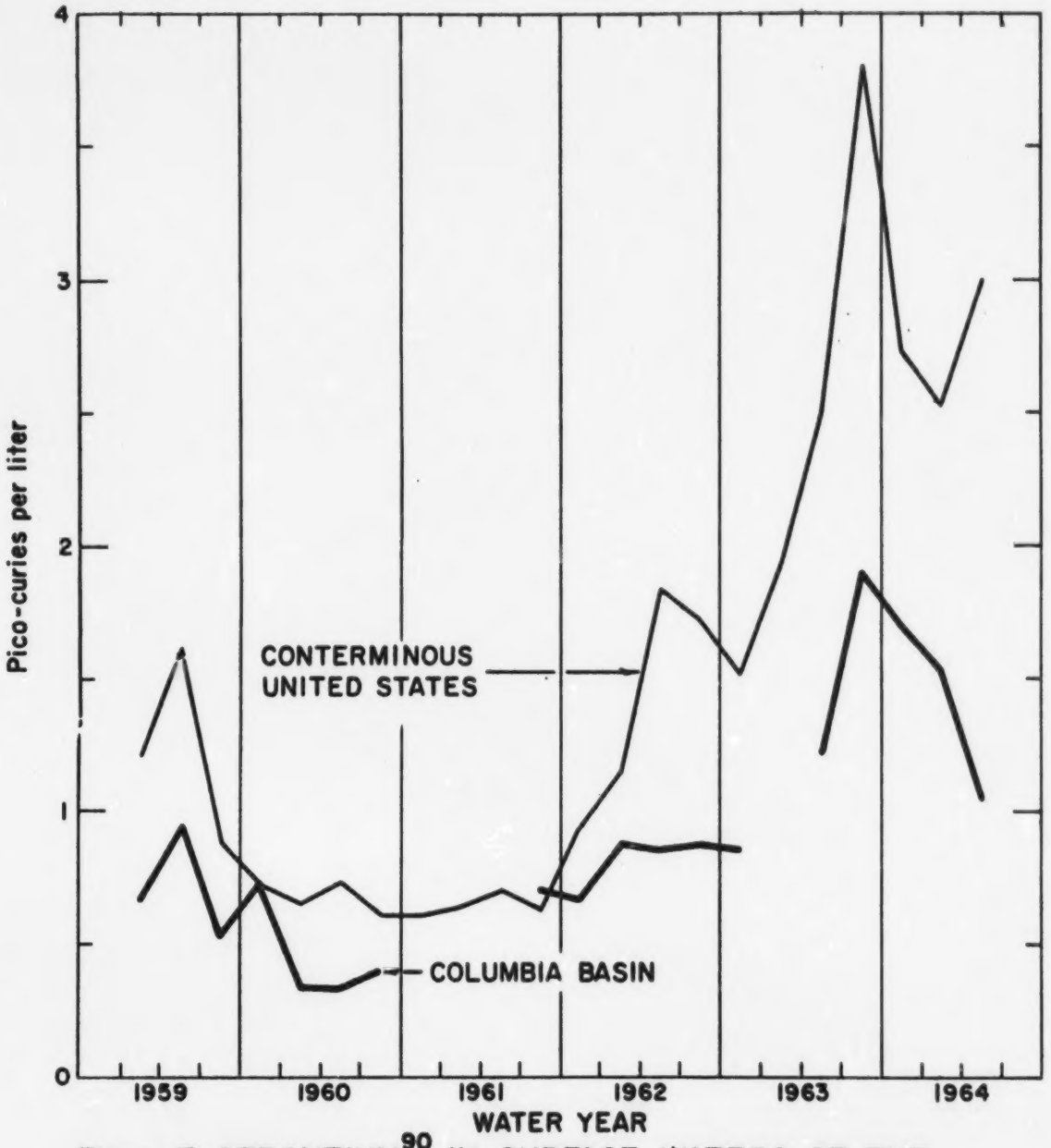
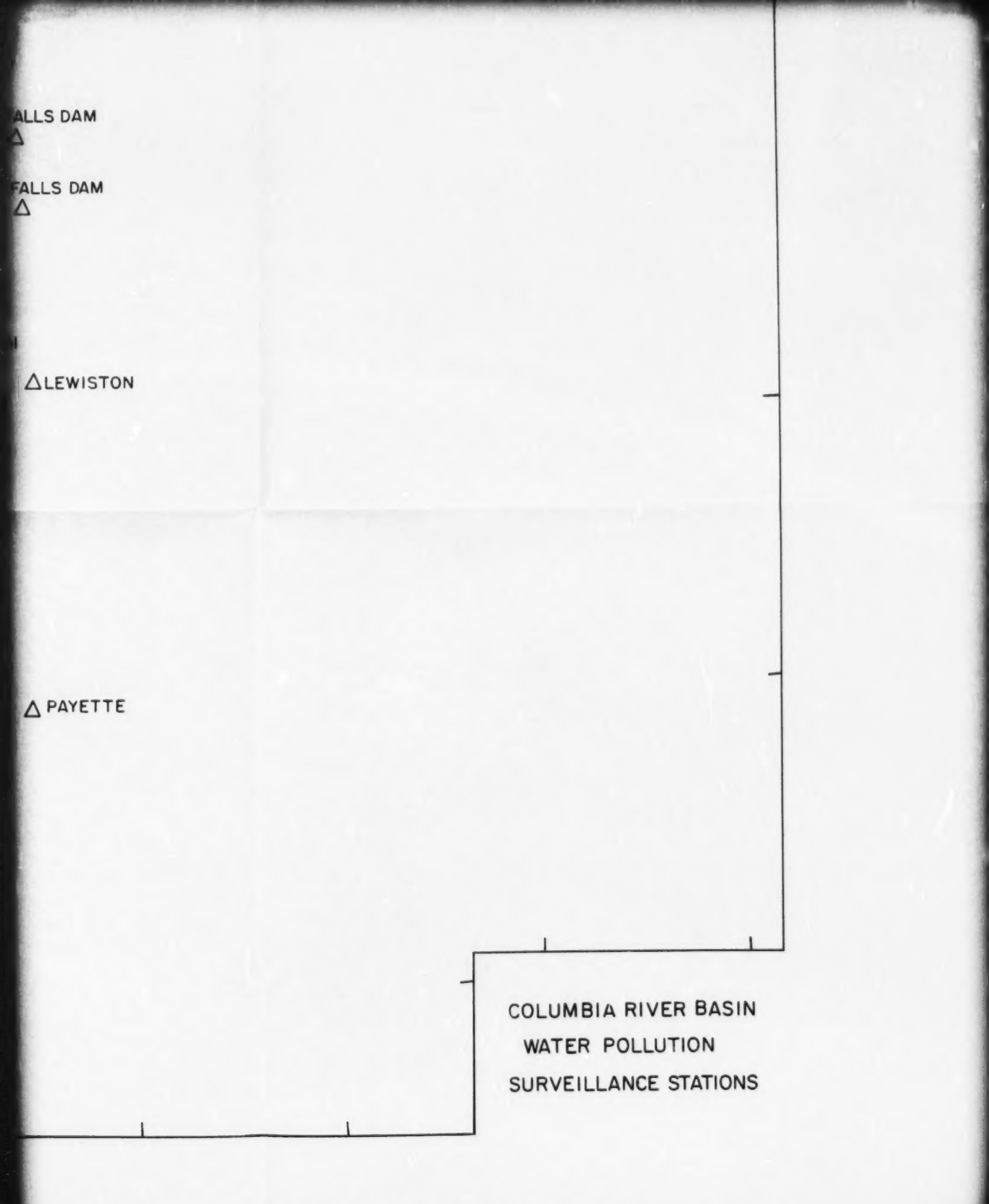
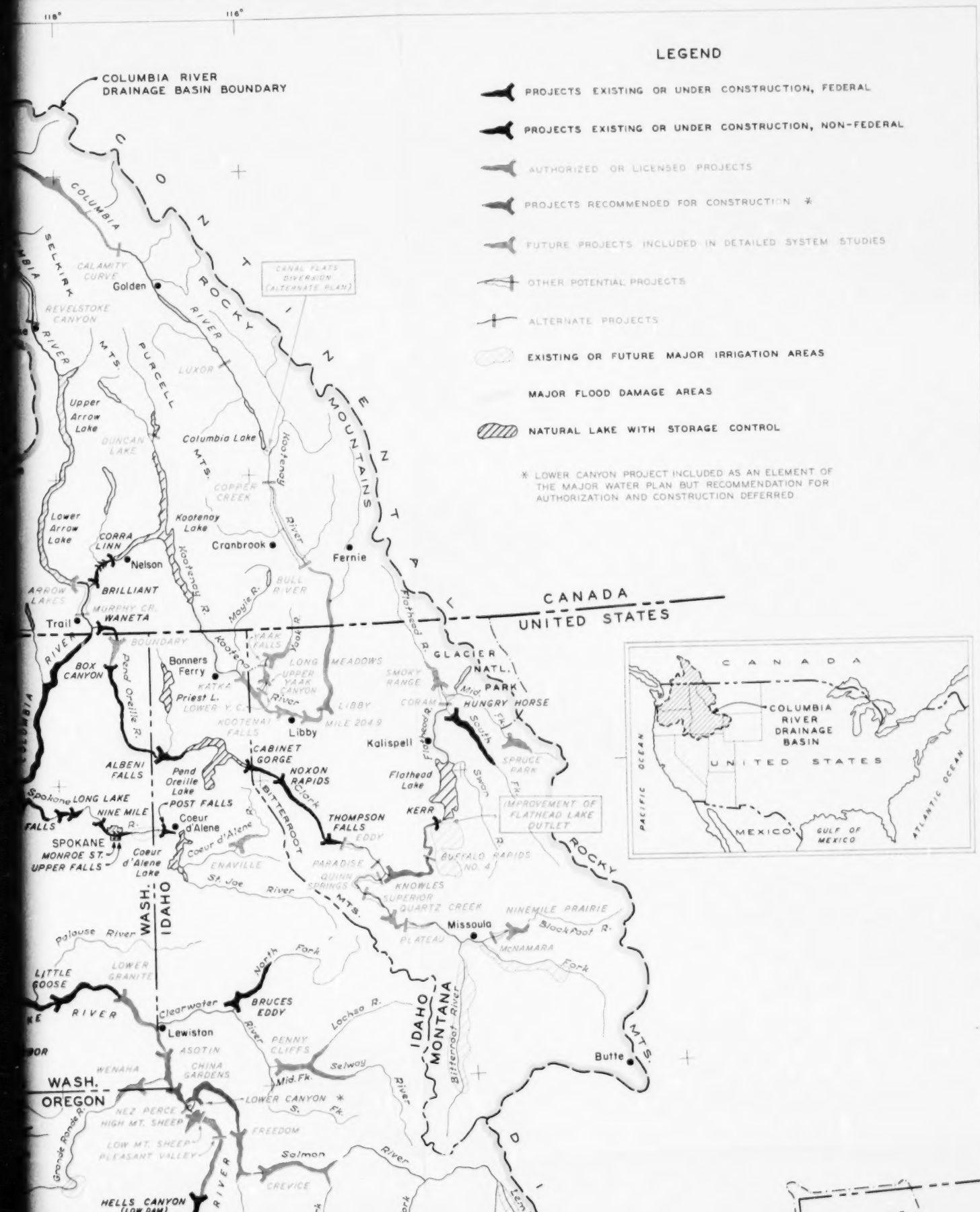


Figure 7. STRONTIUM^{90} IN SURFACE WATERS OF THE COLUMBIA RIVER BASIN AND THE CONTERMINOUS UNITED STATES.

NORTHPORT
ALBENI FALLS DAM
POST FALLS DAM
WENATCHEE
WAWAWAI
LEWISTON
CLATSKANIE
RICHLAND
ICE HARBOR DAM
PASCO
Mc NARY DAM
BONNEVILLE
PORTLAND
PAYETTE


ALLS DAM
FALLS DAM
LEWISTON
PAYETTE
COLUMBIA RIVER BASIN
WATER POLLUTION
SURVEILLANCE STATIONS

128°
124°
122°
120°
118°
52°
50°
48°
46°
FRASER RIVER
MONASHEE
MOUNTAINS
MICA
COLUMBIA
SELKIRK
DOWNIE CREEK
REVELSTOKE CANYON
Revelstoke
Shuswap Lake
North Fork
South Fork
Thompson River
Upper Arrow Lake
Lower Arrow Lake
Okanagon Lake
Kettle River
Similkameen R.
Princeton
Penticton
ARROW LAKES
Trail
BOX CANYON
VANCOUVER ISLAND
VANCOUVER
BRITISH COLUMBIA
WASHINGTON
Bellingham
Victoria
Everett
SEATTLE
TACOMA
OLYMPIA
OLYMPIC MTS.
OCEAN
CASCADE RANGE
Methow R.
Okanogan
Omak Lake
Sanpoil R.
Lake Chelan
WELLS
GRAND COULEE
CHIEF JOSEPH
CHELAN
Chiwawa
CHIWAWA PLAIN
Wenatchee R.
GRAND COULEE EQUALIZING RESERVOIR
LITTLE FALLS
SPOKANE
MONROE ST.
UPPER FALLS
ROCKY REACH
Wenatchee
ROCK ISLAND
WANAPUM
Naches R.
Yakima R.
Tieton R.
Yakima
PRIEST RAPIDS
LOWER MONUMENTAL
LITTLE GOOSE
Palouse River
MAYFIELD
MOSSYROCK
Cowlitz River
Richland
Pasco
SNAKE RIVER
ICE HARBOR
Walla Walla
WASH.
OREGON
Astoria
Longview
Lewis River
SWIFT
YALE
MERWIN
White Salmon R.
BONNEVILLE
Vancouver
THE DALLES
JOHN DAY
COLUMBIA RIVER
McNARY
Umatilla River
Pendleton
PORTLAND
The Dalles
Clackamas River
CLACKAMAS DEVELOPMENT
Grande Ronde R.


LEGEND
PROJECTS EXISTING OR UNDER CONSTRUCTION, FEDERAL
PROJECTS EXISTING OR UNDER CONSTRUCTION, NON-FEDERAL
AUTHORIZED OR LICENSED PROJECTS
PROJECTS RECOMMENDED FOR CONSTRUCTION *
FUTURE PROJECTS INCLUDED IN DETAILED SYSTEM STUDIES
OTHER POTENTIAL PROJECTS
ALTERNATE PROJECTS
EXISTING OR FUTURE MAJOR IRRIGATION AREAS
MAJOR FLOOD DAMAGE AREAS
NATURAL LAKE WITH STORAGE CONTROL
* LOWER CANYON PROJECT INCLUDED AS AN ELEMENT OF THE MAJOR WATER PLAN BUT RECOMMENDATION FOR AUTHORIZATION AND CONSTRUCTION DEFERRED
COLUMBIA RIVER DRAINAGE BASIN BOUNDARY
CANADA
UNITED STATES
CANADA
COLUMBIA RIVER DRAINAGE BASIN
UNITED STATES
PACIFIC OCEAN
ATLANTIC OCEAN
MEXICO
GULF OF MEXICO
CONTINENTAL DIVIDE
ROCKY MOUNTAINS
SELKIRK MTS.
PURCELL MTS.
COLUMBIA RIVER
ROCKY MTS.
BITTERROOT MTS.
CANAL FLATS DIVERSION (ALTERNATE PLAN)
IMPROVEMENT OF FLATHEAD LAKE OUTLET
Golden
Revelstoke
Upper Arrow Lake
Lower Arrow Lake
Columbia Lake
Kootenay Lake
Cranbrook
Fernie
Nelson
Trail
Bonners Ferry
Libby
Kalispell
Flathead Lake
Missoula
Butte
Lewiston
Clearwater
Spokane
Coeur d'Alene
Coeur d'Alene Lake
Pend Oreille Lake
Priest L.
Albeni Falls
Cabinet Gorge
Noxon Rapids
Thompson Falls
Kerr
Hungry Horse
Glacier Natl. Park
Box Canyon
Waneta
Brilliant
Corra Linn
Libby
Bruces Eddy
Penny Cliffs
Lower Canyon *
Hells Canyon (Low Dam)
Dworshak
Grande Ronde R.
Salmon River
Selway River
Lochsa R.
Bitterroot River
Clark Fork
Flathead R.
Kootenai R.
Moyie R.
Pend Oreille R.
Palouse River
St. Joe River
Blackfoot R.
McNamara Fork
North Fork
Mid. Fk.
S. Fk.
WASH.
IDAHO
MONTANA
OREGON
Long Lake
Nine Mile
Post Falls
Spokane Falls
Monroe St. Upper Falls
Little Goose
Lower Granite
Asotin
Wenaha
China Gardens
Nez Perce
High Mt. Sheep
Low Mt. Sheep
Pleasant Valley
Freedom
Crevice
Ninemile Prairie
Quartz Creek
Knowles
Superior
Paradise
Quinn Springs
Enaville
Buffalo Rapids No. 4
Swan
Spruce Park
Coram
Smoky Range
Libby
Mile 204.9
Kootenai Falls
Yaak Falls
Long Meadows
Upper Yaak Canyon
Katka
Lower Y. C.
Murphy Cr.
Arrow Lakes
Duncan Lake
Luxor
Copper Creek
Calamity Curve
Bull River
Boundary
118°
116°
46°

BRITISH COLUMBIA
WASHINGTON
Bellingham
Victoria
Everett
SEATTLE
TACOMA
OLYMPIA
OLYMPIC MTS.
PACIFIC OCEAN
CASCADE RANGE
COAST RANGE
Wenatchee
Lake Chelan
WELLS
CHIEF JOSEPH
GRAND COULEE
COLUMBIA RIVER
BOX CANYON
Trail
WANETA
ALBENI FALLS
Spokane
LONG LAKE
NINE MILE
LITTLE FALLS
SPOKANE
MONROE ST.
UPPER FALLS
Coeur d'Alene Lake
ROCKY REACH
ROCK ISLAND
WANAPUM
PRIEST RAPIDS
LOWER MONUMENTAL
LITTLE GOOSE
LOWER GRANITE
SNAKE RIVER
ICE HARBOR
Yakima
Richland
Pasco
Walla Walla
WASH.
OREGON
WASH.
IDAHO
Palouse River
Tieton R.
Naches R.
Yakima River
MAYFIELD
MOSSYROCK
Cowlitz River
Longview
Astoria
Lewis River
SWIFT
YALE
MERWIN
BONNEVILLE
White Salmon R.
Vancouver
PORTLAND
THE DALLES
JOHN DAY
McNARY
Umatilla River
Pendleton
Grande Ronde R.
The Dalles
Clackamas R.
CLACKAMAS DEVELOPMENT
SALEM
Willamette River
Deschutes River
John Day River
North Fork
South Fork
Baker
HELLS CANYON (LOW DAM)
WALLOWA MTS.
OXBOW
BROWNLEE
DETROIT
FOSTER
GREEN PETER
SCIO
MILLER CR.
HILLS GATE CREEK
BLUE RIVER
LEABURG
FERN RIDGE
WALTERVILLE
FALL CR.
LOOKOUT POINT
COUGAR
Eugene
RAISING OF FERN RIDGE
DORENA
COTTAGE GROVE
HILLS CREEK
PELTON
ROUND BUTTE
Bend
Crooked R.
WICKIUP
Malheur River
OWYHEE
WARM SPRINGS
Owyhee
STEENS MTS.
Coos Bay
COLUMBIA RIVER DRAINAGE BASIN BOUNDARY
Medford
Klamath Falls
OREGON
CALIFORNIA
NEVA
OREGON
IDAHO
SCALE IN MILES
50 0 50
48°
46°
44°
42°
124°
122°
120°
118°

COLUMBIA RIVER AND TRIBUTARIES

BASIN MAP

MAJOR DAM AND RESERVOIR DEVELOPMENT

U. S. ARMY ENGINEER DIVISION, NORTH PACIFIC
CORPS OF ENGINEERS
1963